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A system to measure the kinematics, kinetics and effort of dragon boat paddling

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Abstract

The aim of this project was to develop a system to measure the kinematics, kinetics and effort of dragon boat paddling. A dragon boat seat simulator was developed and mounted to a marina pontoon to reproduce the boat seat paddling geometry relative to the water for stationary paddling. Video cameras, placed in appropriate locations on the pontoon, recorded the 3 dimensional movements of paddlers. A custom built strain gauged paddle measured the paddling forces. Effort was measured via a heart rate monitor and breathing pattern transducer. Electronic interfacing fed the analogue signals (paddling forces, heart rate and breathing pattern) along with the video synchronisation signal to the laptop data collection system. Data for 6 test subjects of different gender, age and skill level (club to international) are reported for a 30 second maximum effort stationary paddling test along with in-boat paddling forces for 2 senior international level paddlers obtained under simulated dragon boat racing conditions.

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Keywords: Dragon boat; stationary paddling; kinematics; kinetics; effort

1. Introduction

Dragon boat racing is a new team sport [1] born of ancient Chinese traditions [2]. For more than two thousand years dragon boat racing was centered on the annual Dragon Boat Festival held on the fifth day of the fifth lunar month [3]. In the modern era its importance gradually waned until 1976, when the Hong Kong Tourist Association initiated a program with the Fishermen's Society of Hong Kong to revive the dragon boat festival, along with all its Taoist traditions as means of promoting Hong Kong [4]. Overseas teams were invited to participate and through the participation of overseas teams a religious cultural event

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on the verge of extinction was transformed in less than 30 years into an international team sport practiced by people of all ages in over 60 countries.

Dragon boat teams consist of twenty paddlers sitting in pairs on fixed wooden benches, a drummer at the front on a ceremonial seat who drums and urges the paddlers on, and a helm who stands at the rear and steers the boat via a long sweep oar. International Dragon Boat Federation rules of racing specify the use of standard boats and paddles and require paddlers to sit, not stand in the boat (in some parts of Asia, under local rules, paddlers may stand). The paddling technique is dependant on the rules of racing, seating geometry in the boat and the anthropometry and physiology of the paddler. Paddling involves the whole body. The hydrodynamic force developed on the blade of the paddle is transferred through the arms, shoulders, back and legs of the paddler onto the boat. How effectively this task is done by each paddler, determines the overall performance of the team. Thus paddling technique is a key performance parameter by which paddlers are judged and ranked by coaches.

Each paddling stroke may be divided into four phases; entry, drive, exit and recovery. In order for a dragon boat team to generate maximum propulsive power during a race, these four phases need to be performed in sync by all twenty paddlers. The exit, recovery and entry times during each stroke need to be minimised whilst the drive time is maximised. In addition the projected area of the paddle blade and its velocity in the race direction needs to be maximised during the time the paddle is in the water.

The aim of this study was to develop a system to measure the kinematics, kinetics and effort of dragon boat paddling and to evaluate the system by testing paddlers of different skill level, age and gender.

2. Methods

The components of the dragon boat analysis system, comprised of force measurement on the paddle, video recording for kinematic analyses and measures of effort via heart rate and respiration monitoring, are described here:

2.1. Video

Three handicams (Sony HDR-HC7) record the movements of a paddler during the stationary paddling test. Video files are then transferred to VICON Motus for three dimensional kinematic data analysis.

2.2. Force

The three dimensional forces applied to the paddle (normal, axial and transverse) are measured via an arrangement of strain gauged sensing elements and an associated electronic amplifier module fitted inside the paddle shaft. The amplifier module consists of three instrumentation amplifiers (INA128), zero-ing trim pots and a power supply. A shielded cable connects the paddle to a waterproof enclosure containing an analogue to digital converter (National Instrument USB 6210 DAQ) and a heart rate microprocessor board. Power for all modules is derived from the USB port of the laptop. The output of the amplifier module is sampled by the DAQ and the digital signal is sent as serial data via the USB bus to the laptop.

2.3. Heart rate

Each heart beat of the paddler is detected and transmitted by a non-coded Polar belt T 31 transmitter to the Polar plug-in receiver housed in the waterproof enclosure. For each heart beat the receiver produces an output logic level pulse of approx 30ms duration. The time between pulses is measured by a custom programmed 16F873A PIC microprocessor and converted to a heart rate output signal in the form of a

PWM (pulse width modulated) waveform. This signal is low pass filtered and fed into the DAQ module where it is sampled along with the force and breathing pattern signals before being sent to the laptop by the USB bus. During analysis heart rate was normalised to age related maximum using the recently developed formula 207-0.7*Age [5]. Effort was quantified by Age Normalised Maximum Paddling Heart Rate and Heart Rate Reserve used during the stationary paddling test.

2.4. Breathing pattern

Breathing pattern is detected and measured via the change in circumference of the participant's abdomen/diaphragm [6]. A linear variable capacitance extensometer [7] is used to measure the change in circumference. The capacitance of the extensometer varies directly as a function of length. As the capacitance changes so does the voltage output of the extensometer. This time varying voltage is sampled by the DAQ module and then transmitted as a digital signal by the USB bus to the laptop. Breathing frequency and relative depth of breathing with respect to at rest breathing is calculated from the voltage output waveform. Effort was quantified by the relative depth and frequency of breathing.

2.5. Synchronisation

Video and analogue data are stored on separate recording systems so a means of synchronisation is required. To achieve this, a Peak RVSU (Remote Video Synchronisation Unit) is used. Immediately before each paddling test the trigger button on the RVSU is manually depressed producing two simultaneous outputs; a 1KHz tone burst of 50 msec duration and a logic level pulse of amplitude 5 volts. The tone burst output is wired to the microphone input of a miniature radio transmitter and the RVSU logic level sync pulse is connected to the DAQ system as a sixth analogue channel. For each handicam there is an associated miniature radio receiver that is tuned to the frequency of the transmitter. The analogue output of the receiver is wired to the external microphone input of the handicam and the 1 KHz tone burst is recorded on the audio track of the mini DV digital video cassette tape within the handicam.

2.6. DAQ (analogue to digital conversion)

The analogue signals (normal, axial and transverse paddle forces, heart rate, breathing pattern and synchronisation pulse) are sampled and converted to digital form by the NI 6210 DAQ module and sent to the laptop via the USB bus.

2.7. Laptop

A custom Labview program residing on the laptop controls the acquisition of the 6 analogue signals connected to the DAQ module. This data is collected at 200 Hz, time stamped, and saved in a spread sheet for subsequent analysis.

These seven components form the basis of a dragon boat paddling analysis system by which the kinematics, kinetics and effort of dragon boat paddling was measured. The system was evaluated via a dragon boat seat simulator mounted to a marina pontoon so that the seating geometry for the stationary paddling test replicated the in-boat seating position of the paddler relative to the water. The force component of the system was also evaluated in a dragon boat under simulated racing conditions. For the stationary paddling test video, heart rate, breathing pattern and force data were collected. However for the in-boat paddling test only force data was measured.

3. Results

The maximum effort paddling test results for three male subjects are shown in Table 1.

Table 1. Maximum effort paddling test results for three male subjects of different age, skill and fitness level.

MAXIMUM EFFORT	MALES			
STATIONARY PADDLING TEST	24 yr old	63 yr old		29 yr old
1 min rest 30sec paddling 1 min recovery	International	International		Club
Type of Test	*Stationary*	*Stationary*	*In-boat*	*Stationary*
Height, cm	191	182		177
Weight, Kg	102	84		93
Body Mass Index	28	25.4		29.7
Age max HR per min = 207 – 0.7*Age	190	163		187
Ave resting HR per min	65	91		96
Max paddling HR per min	159	156		165
Age normalized Max paddling HR per min	0.84	0.96		0.88
Paddling Effort = Hear Rate Reserve used	0.75	0.9		0.76
Heart Rate after one min Recovery	111	102		101
Incremental H R Recovery after one min	48	54		64
Ave Breathing Amplitude at Rest	0.015	0.051		0.018
Breathing Amplitude Ratio for Paddling	12.7	2.6		3.5
Breathing Amplitude Ratio for Recovery	8.0	1.86		1.94
Ave Breathing Rate per min at Rest	18	18		18
Ave Breathing Rate per min for Paddling	55	46		50
Ave Breathing Rate per min for Recovery	25	23		27
Ave Paddling Stroke Rate per min	55	46	74	50
Ave Max Force per stroke, N	695	465	366	404
Ave Min Force per stroke, N	-54	-40	-57	-36
Ave Force Curve Efficacy per stroke	0.66	0.65	0.5	0.61
Ave Propulsive Impulse per stroke, N.s	420	347	136	231
Test Duration Impulse Efficacy	0.995	0.993	0.963	0.984
One min Ave Impulse Workload, N.s/min	23100	15962	10016	11550

Definitions:

Age normalised Max paddling HR = Max paddling HR / Age max HR

Heart Rate Reserve = [Max paddling HR – Ave resting HR] / [Age max HR – Ave resting HR]

Incremental HR recovery one min after test = Max paddling HR – HR after one min Recovery

Force Curve Efficacy per stroke = Ave Force per stroke / Max Force per stroke

Propulsive Impulse per stroke = Area under Force–Time graph per stroke

Test Duration Impulse Efficacy = [sum of positive Impulses – sum of negative Impulses] / sum of positive Impulses

One min Ave Impulse Workload = Ave Propulsive Impulse per stroke * Stroke Rate

The maximum effort paddling test results for three female subjects are shown in Table 2.

Table 2. Maximum effort paddling test results for three female subjects of different age, skill and fitness level.

MAXIMUM EFFORT	FEMALES			
STATIONARY PADDLING TEST	32 yr old	32 yr old		32 yr old
1 min rest 30sec paddling 1 min recovery	International	International		International
Type of Test	*Stationary*	*Stationary*	*In-boat*	*Stationary*
Height, cm	165	156		155
Weight, Kg	60	55		52
Body Mass Index	22	22.6		21.6
Age max HR per min = 207 – 0.7*Age	184	173		185
Ave resting HR per min	85	105		63
Max paddling HR per min	155	176		135
Age normalized Max paddling HR per min	0.84	1.02		0.73
Paddling Effort = Hear Rate Reserve used	0.71	1.05		0.59
Heart Rate after one min Recovery	106	95		70
Incremental H R Recovery after one min	49	81		65
Ave Breathing Amplitude at Rest	0.041	0.056		0.071
Breathing Amplitude Ratio for Paddling	2	0.8		2.5
Breathing Amplitude Ratio for Recovery	2.6	0.64		2.5
Ave Breathing Rate per min at Rest	30	14		26
Ave Breathing Rate per min for Paddling	48	51		47
Ave Breathing Rate per min for Recovery	25	44		29
Ave Paddling Stroke Rate per min	48	51	72	47
Ave Max Force per stroke, N	266	268	263	182
Ave Min Force per stroke, N	-39	-41	-62	-28
Ave Force Curve Efficacy per stroke	0.59	0.58	0.6	0.5
Ave Propulsive Impulse per stroke, N.s	165	152	86	94
Test Duration Impulse Efficacy	0.982	0.976	0.943	0.972
One min Ave Impulse Workload, N.s/min	7920	7752	6163	4418

Definitions:

Age normalised Max paddling HR = Max paddling HR / Age max HR

Heart Rate Reserve = [Max paddling HR – Ave resting HR] / [Age max HR – Ave resting HR]

Incremental HR recovery one min after test = Max paddling HR – HR after one min Recovery

Force Curve Efficacy per stroke = Ave Force per stroke / Max Force per stroke

Propulsive Impulse per stroke = Area under Force–Time graph per stroke

Test Duration Impulse Efficacy = [sum of positive Impulses – sum of negative Impulses] / sum of positive Impulses

One min Ave Impulse Workload = Ave Propulsive Impulse per stroke * Stroke Rate

4. Discussion

4.1. Heart rate

Only two participants reached a HRmax > 90% and HRR > 85% and these were the mature age international paddlers who had performed this test a number of times on previous occasions whilst the other test subjects were first time participants. Experience and learning may play a role in enabling participants to produce maximum effort. Heart rate recovery after one minute rest was notably greater for all participants than the 21 BPM minimum acceptance criteria set by the medical profession [8].

4.2. Breathing pattern

For all participants the breathing rate during paddling was entrained on a 1:1 ratio with the paddling rate. Entrainment took place within the first three strokes and in some cases a phase shift occurred during the latter stages of the 30 second max effort stationary paddling test possibly due to the onset of fatigue.

4.3. Paddling stroke rate

The average stroke rate of participants during the stationary paddling test varied from 46 to 55 strokes per minute. This compares with a dragon boat stroke rate of 80 to 90 reported in [9] [10], 72 to 80 reported for in-boat paddling in Table 1, a canoe stroke rate of 50 estimated from data in[11] and a kayak stroke rate of 115 to 136 reported in [12]. It appears that a stationary paddling stroke requires more time to complete than an in-boat paddling stroke. This may be due to the greater stroke length that stationary paddling permits. In-boat paddling looses stroke length due to boat movement. However the first stroke of a dragon boat race can be considered to be a stationary paddling stroke since the boat is stationary.

4.4. Paddling force

There is no comparison data in the literature for stationary dragon boat paddling but the in-boat paddling forces (263 N to 366 N) in Table 1 are comparable with the only data reported in the literature (306 N for elite and 203 N for sub-elite) [9]. These values are similar to elite canoeists (260 N and 351 N) [11] and are larger than those for elite kayakers (200 N to 210 N) [13]. Force Curve Efficacy (FCE) provides a measure of the variations of individual force profiles. The stationary paddling average FCE ranged from 0.50 for the club level female to 0.66 for the 24 yr old male international. The in-boat average FCE was 0.50 for the male and 0.60 for the female senior international. These values are slightly larger than the 0.48 value reported for both elite and sub-elite paddlers in the literature [9] [10]. At the end of each stroke a negative force develops on the paddle for both stationary and in-boat paddling. This negative force has not been reported in the literature.

4.5. Paddling impulse

Test Duration Impulse Efficacy (TDIE) for the stationary paddling test is highest for the international level paddlers. For the in-boat case the TDIE is ~3% below that of stationary paddling, possibly due to the movement of the boat creating a larger negative force on the paddle during extraction. Higher negative forces were measured for the in-boat case and this appears to support the suggested explanation. The Average Propulsive Impulse (API) per stroke for the in-boat tests reached only 39% of the stationary value for the male and 57% for the female senior international. A higher in-boat stroke rate may explain a large part of the drop in API but not all. A decrease in force and or stroke length may explain the rest. The in-boat API for the senior internationals (136 N.s and 86 N.s) are higher than those reported in the literature for in-boat paddling (55.4 N.s for elite and 34.6 N.s for sub-elite) [9]. The impulse estimates (114 N.s to 148 N.s) derived from canoe data [11] are similar to the senior internationals. Data reported for kayakers (49N.s to 52 N.s) [13] are lower and comparable to those reported for in-boat paddling [9].

4.6. Paddling workload

Using force time data only, the one minute average propulsive impulse (OMAPI) workload provides a measure of the work and effort during paddling (see Table 1 for a definition). The stationary OMAPI workload for the senior internationals was 15962 N.s/min for the male and 7752 N.s/min for the female whereas their in-boat data was considerable less (10016 N.s/min for the male and 6163 for the female) possibly due to a shorter in-boat stroke length.

5. Conclusion

This paper has described a dragon boat paddling analysis system. The instrumentation described appears to provide a suitable method to study the kinematics, kinetics and effort of dragon boat paddling.

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